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Michael,
Jean Carlo asked
me to mail you this
first draft.
Best
Jim Cushing

Reply to Critics

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P. La Rivière and M. Redhead in their contribution to this volume have criticized a paper (Ghirardi, Grassi 1994, 397) in which the EPR argument has been reconsidered within a relativistic framework. The purpose of our paper was to show that one cannot claim, with Einstein, that the assumptions that Quantum Mechanics is correct (QM) and complete (Compl) imply to accept some kind of *spooky action at a distance* (Born 1971, 158).

To discuss their criticisms and to allow the reader to properly understand the problem it seems appropriate to recall the purpose of our paper and to outline the logical steps we have followed.

1. In the introduction we started by remarking that, in a relativistic context, one cannot make property attribution on the basis of the "possibility of predicting" since for the case of space-like separation, there is no absolute time ordering. Thus we have proposed, as other authors had done, to relate property attribution to the possibility of making true counterfactual assertions (La Rivière and Redhead (LRR) agree on this point). Then, in Section 2, which represents the first part of the paper and the one which they criticize, we have reconsidered the EPR argument from this point of view. After some preliminary remarks in the introductive Subsections we have tackled our problem.

2. Subsection 2.4 deals with the Galilean case with the purpose to show how one has to proceed in reformulating the EPR argument in a nonrelativistic context in the language of counterfactuals.

3. The subsequent Subsection 2.5 is devoted to the analysis of the relativistic case when a precise locality assumption is made. Before

coming to describe our arguments in this part of the paper it is appropriate to focus some points and to list the related criticisms by LRR. As just stated we have put forward a locality assumption we have called L-Loc, and then we have argued on its basis. Here comes the first criticism (we will list all criticisms of LRR by the letter c followed by a number and similarly we will denote by r followed by a number the corresponding reply):

c1) That we have not given the necessary emphasis to the fact that the locality assumption we call L-Loc (a shortcut for Lorentz locality) is actually the conjunction of two logically independent locality assumptions:

$$(L-Loc) \equiv (OM-Loc) \wedge (ER-Loc). \qquad (1)$$

Such assumptions play quite different roles in our derivation and our not having been sufficiently explicit on this point makes our paper obscure.

r1) We plainly admit that our paper would have been more easily understandable if we would have introduced explicitly the terms (OM – Loc) and (ER – Loc) and made specific reference to them. But this has nothing to do with our argument being correct. Moreover, even though it is true that we have not written a precise formal expression like the above, there is no doubt that in our definition such a distinction is clearly made. Actually, the authors themselves define the terms (OM – Loc) and (ER – Loc) using the expressions of our paper:

(OM – Loc) is the assumption that the outcome obtained in a measurement cannot be influenced by measurements performed in space-like separated regions

(ER – Loc) is the assumption that possessed elements of physical reality referring to a system cannot be changed by actions taking place in space-like separated regions.

4. We then went on reproducing the EPR argument about the incompleteness of the theory in the considered relativistic context with the locality assumption. In doing so we have accepted that (OM – Loc) licenses the use of the Principle of Local Counterfatual Definiteness (PLCD). And here comes the second criticism by LRR.

c2) La Rivière and Redhead consider this use of PLCD illegitimate (even though they recognize that this claim is not uncontroversial and actually that Lewis himself, one of the greatest experts in the field, does not share their position). As a consequence our conclusion would be limited to deterministic systems.

r2) To answer to this remark we feel the necessity to call attention to the fact that the purpose of Subsection 2.5 was twofold. First of all, since we were well aware that Redhead's position about counterfactuals is controversial, we considered interesting to see whether the adoption of Lewis' position on this matter would allow, also in the case under consideration, to run the argument leading to the proof of incompleteness of quantum theory. We have made clear that, since we had assumed (L – Loc), which includes (OM – Loc) we could use PLCD. All is very simple and one reaches the desired conclusion:

$$QM \wedge (L - Loc) \supset \neg Compl. \qquad (2)$$

We stress that in our paper we have made clear that at this stage we were in line with Lewis' position (which we actually share).

The second purpose of the analysis of the considered Subsection was to call attention to the different role played by the locality assumption in the relativistic case with respect to the Galilean one.

With reference to our argument of Section 2 LRR raise also a criticism which seems to us having no reasonable ground:

c3) That we made a logical blunder since, according to them, we would have claimed that one cannot turn conclusion (2) into

$$QM \wedge Compl \supset \neg(L - Loc). \qquad (3)$$

r3) Concerning this point we firmly stress that we have never denied (3) and that the sentence the authors quote from our paper to support their criticism actually states that, in a relativistic context, it is not possible to claim that *there is istantaneous creation of properties at-a-distance*. This obviously does not amount to state that it is not possible to prove $\neg(L - Loc)$ but that it is not possible to prove $\neg(ER - Loc)$. Further support

to the present claim comes from the following remarks. The central and crucial Subsection of the first part of the paper, i.e. 2.6, begins exactly by mentioning the results of Subsections 2.4 and 2.5 and exhibiting explicitly eq.(3). In the paper we have purposedly dropped the specification whether we were dealing with G or L-Loc since, at this point, the conclusion was correct for both cases. However, as it is evident from our paper, there is an important difference between the consequences of denying G-Loc or L-Loc. In fact, on one side, from the very beginning, i.e. in the introduction, we have made absolutely clear that in the Galilean case the EPR argument, when completeness is assumed, implies $\neg$(ER – Loc): *the burden of the EPR argument is that, in a sense, even standard quantum mechanics with the completeness assumption exhibits a form of parameter dependence concerning these elements of physical reality. Roughly speaking, one could state that in a situation like the one discussed above, one could freely decide, by simply switching on an apparatus, whether to create, instantaneously, a property of a system far away*. On the other hand the very core of our argument, which we had already anticipated in Subsection 2.3, was to stress that in a relativistic context the situation is radically different: *In fact, our aim in this Section (*2. Reconsidering the EPR Argument in a Relativistic Context*) is simply to show that the completeness assumption about quantum theory does not imply that, in EPR-like situations, something real concerning the system at L (R) is being created as a consequence of a measurement on the system at R (L), the act of measurement being space-like with respect to the distant system*. This fundamental difference between the two cases derives from the fact that (L – Loc) is the conjunction of (OM – Loc) and (ER – Loc) which, in a relativistic context and, as appropriately stressed by LRR, are both necessary conditions to reach conclusion (2).

5. At this point comes the central Subsection 2.6 of the first part of our paper in which we draw our conclusion about the impossibility of proving $\neg$(ER – Loc). We will outline our reasoning in a moment. We start by presenting the central criticism by LRR to our thesis.

c4) According to the authors our argument that it is not possible to prove $\neg$(ER – Loc) does not follow. Even more, they state: *if we follow Ghirardi and Grassi's own reasoning, then the argument* ***does demonstrate a violation*** *of* (ER – Loc).

r4) This sentence shows clearly that the authors not only have not grasped our thesis but also that they argue incorrectly. As we are going to show, their criticism rests on not keeping in mind the logical difference between claiming that it is not possible to prove A and that it is possible to prove $\neg$A. In fact, according to (1), we can rewrite (3) as:

$$(QM \wedge Compl) \supset \neg(OM - Loc) \vee \neg(ER - Loc) \qquad (4)$$

Assuming that $(QM \wedge Compl)$ is true, there are, therefore, three alternatives compatible with (4):

a) $(OM - Loc)$ is false and $(ER - Loc)$ holds true,

b) $(OM - Loc)$ is true and $(ER - Loc)$ is false,

c) both $(OM - Loc)$ and $(ER - Loc)$ are false.

It is extremely important to stress that in order to falsify our thesis one should prove that alternative a) is impossible and it is by no means sufficient to claim or to prove that b) or c) are possible. In fact our thesis is not that $(ER - Loc)$ holds true, it is that one cannot legitimately derive $\neg(ER - Loc)$ from the premises. This is the elementary logical point that the authors have missed, as it appears clearly from their argument which should, in their opinion, put into evidence our logical blunder. They call attention to the fact that

$$QM \wedge (OM - Loc) \wedge (ER - Loc) \supset \neg Compl \qquad (5)$$

could be used in following way **to derive** $\neg(ER - Loc)$:

$$QM \wedge Compl \wedge (OM - Loc) \supset \neg(ER - Loc), \qquad (b')$$

i.e. that there is spooky action at a distance. We remark that (5) could also be used to get

$$(QM \wedge Compl) \wedge (ER - Loc) \supset \neg(OM - Loc). \qquad (a')$$

Obviously (a') and (b') are the equivalent of a) and b), respectively. However, as discussed previously, the fact that one can derive (b') is absolutely irrelevant for our thesis.

As already stressed, to disprove our thesis one should prove that a) is impossible, i.e. one should prove that our premises, (QM $\wedge$ Compl), under the assumption that (OM – Loc) is false, imply $\neg$(ER – Loc). But that this is not the case is just what we have shown in our paper along the following lines:

i. $\neg$(OM – Loc) implies that one cannot keep fixed, in a counterfactual argument and for the case under discussion, the value of the outcome of the measurement at the right wing of the apparatus at t_R, i.e. what we have denoted as $O_R(t_R)$.

ii. As a consequence one cannot make the conterfactual assertion $M_L(t_L) \Box\!\!\rightarrow O_L(t_L)$.

iii. Consequently one cannot assert that there is an Element of Physical Reality at L at t_L.

iv. Consequently one cannot deduce $\neg$(ER – Loc).

This proves our thesis.

In the final part of their paper LRR claim that they agree with our conclusion, but for different, more appropriate and logically correct reasons. These reasons are simply that they reject Lewis' position. With reference to this point we would like to call attention to the fact that since the structure of our argument is "even if one would accept Lewis' position about counterfactuals one could not prove $\neg$(ER – Loc) from (QM $\wedge$ Compl)", our analysis covers also the trivial case in which one does not accept that PLCD follows from (OM – Loc) .

References:

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